

Daily Activity Patterns and Effects of Environmental Conditions on the Behavior of the Yellowhead Jawfish, *Opistognathus aurifrons* with Notes on its Ecology.

(Plates I-V; Text-figures 1-21; Tables 1-4)

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Quantitative observations of the behavior of *Opistognathus aurifrons* were made at Bimini, Bahamas, for a period of 25 days using an underwater television system. Various activities of this species were described. The activity of feeding was constant during the day, but was reduced during periods of low light intensity and high current speed. The activities of "digging," "chasing," and "arching" varied diurnally, and "digging" and "arching" varied with the current speed.

Light was a controlling factor of the uncovering of the burrow in the morning. Light and interspecific relations determined the time of closing the burrow in the evening. Various burrow-oriented activities showed a peak during dawn or dusk periods. The ranges and territories of individuals were determined. The vertical range varies diurnally. The relationship of *O. aurifrons* to other jawfishes and convergent species of reef fishes was examined.

INTRODUCTION

THE YELLOWHEAD JAWFISH, *Opistognathus aurifrons* (Jordan and Thompson), (Plate I, fig. 1), occurs in the Florida Keys, the Bahamas, and the West Indies (Böhlke and Chaplin, 1968). The species (maximum standard length approximately 94 mm) is found in colonies in areas of calcareous sand substrate near coral outcrops. Its known depth distribution is from 3 to 50 m.

Opistognathus aurifrons was originally described as *Gnathypops aurifrons* by Jordan and Thompson (1905) from a specimen collected at Dry Tortugas, Florida, and placed into the genus *Opisthognathus* when these two genera were shown to be synonymous (Meek and Hildebrand, 1928). Briggs (1961) pointed out that the name *Opistognathus* was used by Cuvier (1817) and that the variation *Opisthognathus* was introduced by Cuvier and Valenciennes (1836) and followed in subsequent works.

Longley and Hildebrand (1941) included some general information about *O. aurifrons*. They described the burrow as "perhaps 300-500

mm deep" and "enlarged below, the shape of the terminal chamber being largely fixed by the arrangement of the larger bits of dead coral by which it is surrounded." One fish was observed in the midst of constructing its burrow and its behavior described. The general feeding behavior was described and its food characterized as planktonic.

Böhlke and Thomas (1961) redescribed *O. aurifrons* and placed in its synonymy *Gnathypops bermudezi* Howell Rivero. They dealt with geographic variation in certain characters of specimens from Florida, the Bahamas, the Virgin Islands, and Cuba. They found Bahamian specimens generally to have black pigment spots on the chin and under the gill membrane at the isthmus, a curved dark line beneath the maxillary and the preopercle, and the branchiostegals edged with duskiness. Specimens from Florida lacked all of these markings, and material collected in the Virgin Island population was found to be intermediate to the Florida and Bahama populations in the number of branched dorsal, anal, and pectoral-fin rays, length of the lateral

line, number of lower gill rakers, and the number of canine teeth. An increase in the number of lower gill rakers with increasing standard length was also found.

Böhlke (1967) reported that one specimen of a large series taken in the Florida Keys (UMML 18904) showed all the black head markings characteristic of Bahamian individuals.

Böhlke and Thomas (1961) also dealt with the tear drop shape of the pupil of *O. aurifrons*. The long axis of the pupil is oriented horizontally when the fish is in a normal vertical "floating" or hovering position, and they thought that this, plus the position of the eyes on the head, allows binocular vision horizontally when the fish is in its normal hovering orientation.

Böhlke and Thomas (1961) reported a depth distribution of from 3 to 30 m. Böhlke (1967) modified this distribution to 3 to 36 m for Bahamian specimens and to 41 m for Florida specimens. The writer has observed *O. aurifrons* at Long Reef, Florida, to a depth of 50 m. Specimens in the Florida Keys are found most often on the seaward side of the outer reefs in depths greater than 7 m. In Bimini, Bahamas, *O. aurifrons* is found on the seaward (west) side of the islands.

Randall (1967a) examined the stomach contents of 16 specimens from the Virgin Islands and determined their food consisted of 85 percent copepods, 9.4 percent shrimp larvae, and small percentages of fish eggs, siphonophores, barnacle larvae, polychaetes, and unidentified animal remains. He also states *O. aurifrons* is diurnal and "covers the entrance to its burrow for the night by backing in with a large stone in its jaws."

Leong (1967) gave a general account of the breeding and territorial behavior in the yellow-head jawfish. She dealt with fish from the Florida region in aquaria and described both males and females as being territorial, even during pair formation and breeding. Paired fish were allowed to enter one another's territories and burrows; sexual dimorphism in behavior was seen for paired fish. Both fish frequented a third burrow and the male fish led the female to this burrow by performing a lateral display action. Spawning occurred in the burrow and the male orally incubated the eggs. The eggs could be laid down inside the burrow to allow the male to eat. A brooding male was allowed to enter the female's burrow, but the female was not permitted to enter the brooding male's burrow.

There are differences in color pattern of Bahamian and Floridian specimens aside from the already mentioned head markings. Böhlke and Thomas (1961) provided an excellent description of life colors for Florida specimens.

Bahamian specimens as illustrated in Böhlke and Chaplin (1968: 489) and in Plate I, fig. 1 are paler than individuals from Florida. The yellow found on the anterior portion of the body of Florida specimens is much less intense in those from the Bahamas and is practically non-existent in specimens maintained in aquaria for a few weeks. The various dark markings on the head of Bahama individuals, with the exception of the spots on the lower jaw, are normally hidden by various bones and folds of skin. These markings are clearly exposed during various intraspecific activities and are probably important in such activities. Also present on many Bahamian individuals is what may be termed an "eyebars," a broad faint, dark band running dorsally between the eyes and ventrally onto the tip of the lower jaw. Unfortunately this band is seldom visible in preserved material although it is obvious in life.

These important morphologic differences between Bahamian and Florida populations indicate that consistent differences may well exist also in behavior. Therefore this study was devoted when feasible only to the Bahamian population. Some supplementary information was obtained for the Florida population and such is noted in the text.

Since it often is displayed in home and public marine aquaria, much popular literature also exists on *O. aurifrons*. Some of the more noteworthy references to this literature include Ray (1968), Van Doorne (1969), and Kristensen (1965).

MATERIAL AND METHODS

Behavioral observations were made through the use of the University of Miami Rosenstiel School of Marine and Atmospheric Science video-acoustic installation at Bimini, Bahamas. The underwater television system (UTV) consists of a closed circuit television camera and associated hydrophones (Plate II, fig. 2) situated 1.5 kilometers off the west coast of North Bimini at a depth of 20 m with cables leading to a monitor room (Plate II, fig. 3) at the Lerner Marine Laboratory of the American Museum of Natural History. Details of the system can be found in Myrberg et al. (1969).

Daily activity of individual fish was monitored for 30-minute periods every two hours between 7 AM and 7 PM at the start of the study. This schedule was modified in relation to changing day length in order to retain the same relation of periods to total day length as was present at the onset of the activity measurements. The occurrence of specific activities was recorded by marks made upon an Esterline Angus travelling chart recorder and their frequency and/or duration determined from these

records. Measurements of the environmental parameters of current speed, current direction, and water temperature were taken at the same time as the behavioral measurements for possible correlation.

A Hydro Products model 460 current meter, with a useful range of 0.05 to 7.0 knots and an accuracy of ± 3 percent of the reading was used with a model 451 current speed readout module located in the monitor room at the Lerner Marine Laboratory. The rotational speed of the current meter could also be monitored visually on the UTV as a check on the readout system. The direction of the current was determined by observing the direction of motion of particles in the water on the UTV screen.

A Hydro Products model 403A temperature probe, with a measurement range of 0° to 40° C and an accuracy of $\pm 0.5^{\circ}$ C was used with a model 401 readout module located in the monitor room. Identical temperature readings were obtained with those readings taken with a mercury bulb thermometer at the UTV site.

Behavioral observations were made during both dawn and dusk periods. The videcon camera used in the UTV made nocturnal observations impossible without the use of artificial lights.

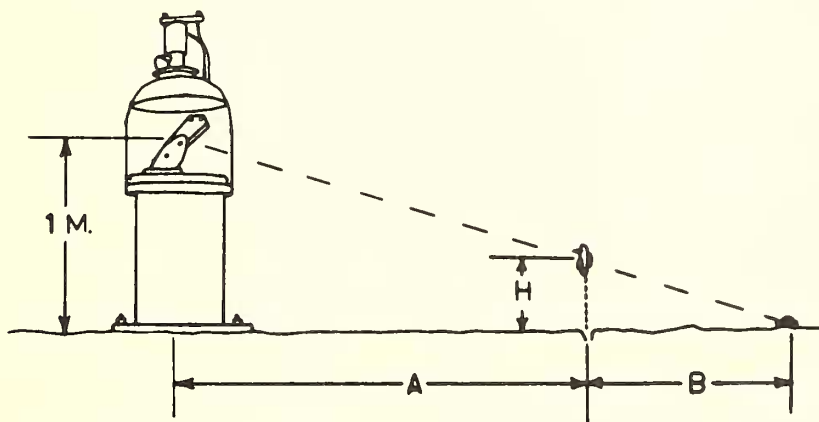
Late in the study an effort was made to determine vertical and horizontal distances travelled by the fish from the burrow by placing a

grid of small markers made from 2.5 inch long carriage bolts at specified distances from the burrow.

Vertical heights above the burrow were measured by markers placed certain distances behind the burrow opening on the line of sight of the camera to the burrow (Text-fig. 1). By knowing the distance from the camera to the burrow, from the burrow to the marker, and the viewing height of the camera off the bottom, the vertical height of the fish could be determined by the use of similar triangles as long as the fish was directly above the burrow. The position of the fish in relation to the burrow was fairly easily determined by the relative size of the fish on the screen and by its image sharpness in the limited depth of field of the camera.

DEFINITION OF BEHAVIORAL ACTIONS

It is necessary to define the actions of the animal which are to be measured. Ideally, the entire behavioral repertoire of an organism should be described. For the purposes of this paper only those actions concerned in the daily activity measurements will be defined. No organizational grouping of behavioral actions used in past studies has apparently fulfilled the needs of subsequent workers since it seems each study has required the modification of a previous or formation of a new hierarchy of actions. This was also true with the behavior of *Opistognathus aurifrons*. The behavior of the animal was di-



TEXT-FIG. 1. The method used for the determination of the height (H) of a jawfish above its burrow at the UTV site. When the fish is in line with the distance marker (C), its height above its burrow in meters equals $\frac{B \text{ in meters}}{A + B \text{ in meters}}$.

vided into six general groups: 1) locomotory movements, 2) burrow oriented, 3) feeding oriented, 4) maintenance activity, 5) interspecific oriented, and 6) intraspecific oriented.

Locomotory Movements

Hover. The fish maintains itself in position above the substrate in an anterior-posterior vertical orientation by an alternate beating of the pectoral fins and a beating of the caudal fin, the posterior one-half of the body, the posterior part of the dorsal fin, and the anal fin. This is shown in Text-fig. 2a and 2b in lateral and ventral views. The dorsal, anal, and caudal fins are moderately spread while the pelvic fins may either be held tightly against the body (Text-fig. 2c) or held out at a right angle from the body (Text-fig. 2d).

The movements of the pectoral and caudal fins are co-ordinated so that the thrust produced by the motion of the caudal fin and the posterior portion of the body counteracts the tendency by the stroke of one of the pectoral fins to move the upper torso laterally. In this manner the cephalic portion of the body is maintained in a stable position.

The pelvic fins are held out from the body most often during periods of very low current speed. The extension of the pelvic fins may well aid in balancing the animal. This is the typical fin position assumed by fish in aquaria since currents there are practically non-existent. At current speeds greater than 0.03 knot the pelvic fins are usually held posteriorly against the body.

The density of seven live Florida specimens was determined utilizing a beam balance for weight determination and a graduate cylinder for volume measurement. A mean value of 1.04 g per cm³ was obtained which makes *O. aurifrons* slightly denser than sea water (1.02 to 1.03 g per cm³). Fish in aquaria under conditions of zero current speed were observed to stroke each pectoral fin at a rate of 80 to 95 strokes per minute in order to maintain a stationary position in the water column. The animal produces forward (upward) thrust with movements of the pectoral fin as shown in Text-fig. 3. The dorsal and ventral rays of the pectoral fin are brought forward while the medial rays of the fin lag (Text-fig. 3a) on the upstroke. On the downstroke all of the rays are brought back together (Text-fig. 3b).

To maintain its hovering position above the burrow during periods of high current speed, the fish must swim at an angle to the vertical with its head oriented into the current. The angle of the anterior-posterior axis of the body with the vertical increases with the intensity of the current. At zero current speed this angle is zero degrees, at 0.15 knot the angle is 45 de-

grees, at 0.20 knot the angle is 60 degrees, and at 0.25 knot the angle is 75 degrees. Currents over 0.30 knot in speed require *O. aurifrons* to swim practically horizontally in the water column. The beating rate of the pectoral and caudal fins is consequently increased during periods of increased current speed.

Movement Forward and Rearward. Forward movement by *O. aurifrons* is accomplished by simply increasing the beating rate of the caudal and pectoral fins. Rearward movements, however, can be carried out in several ways. The fish can move downward (usually rearward) by decreasing the fin beating rate. The fish can also move rearward due to its density being greater than seawater and reducing resistance to rearward movement by folding the pectoral fins forward. Finally it is possible for the animal to propel itself rearward by beating the pectoral fins in a reverse manner from that used in forward movement.

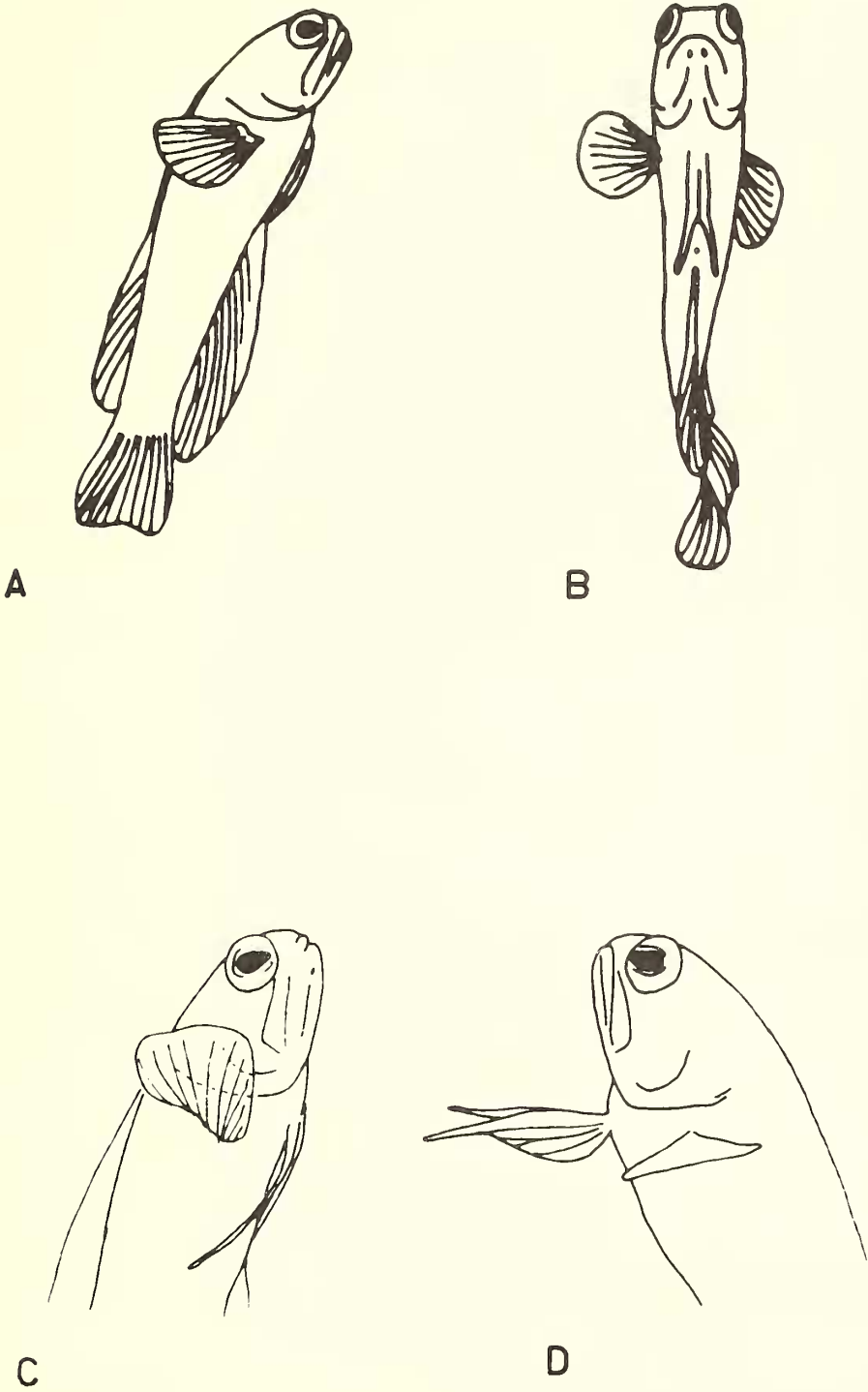
Turn (Maneuvering) in the Hover (roll, pitch, yaw). Lateral turning (yaw) from the hover is accomplished by lessening the thrust or missing completely one or more strokes by one pectoral fin and bending the body laterally (Text-fig. 4). The thrust differential produced causes the body to turn laterally toward the side of lessened thrust.

Roll and pitch are accomplished in different manners. On the alternating downstrokes of the pectoral fins, either the dorsal or ventral rays can be brought back first. If this is done, the thrust produced is not on a line with the body axis. If the ventral portions of both pectoral fins are brought back first, a pitch in the ventral direction is accomplished. If the dorsal portions are brought back first, the pitch is in the dorsal direction. If the dorsal portion of one pectoral fin and the ventral portion of the other are brought back first, a roll is produced. What is henceforth referred to as a "turn" is a turning of the animal in the water column which can involve any or all of the roll, pitch, and yaw movements described.

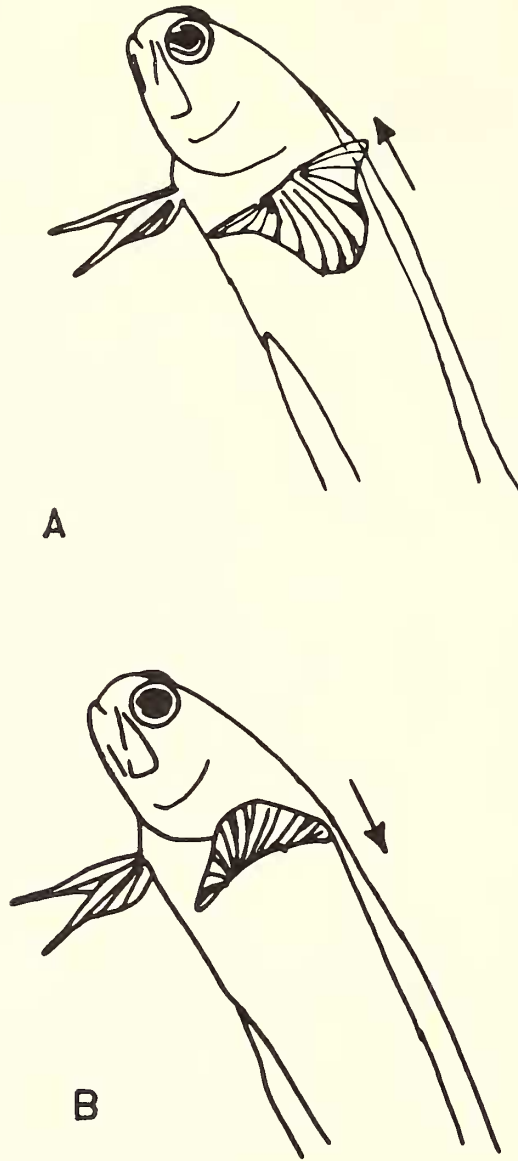
Burrow Oriented Actions

Burrow oriented actions fall into two general categories: 1) those concerned with the burrow as a refuge from predators and a nocturnal resting place, and 2) those actions concerned with maintenance of the burrow.

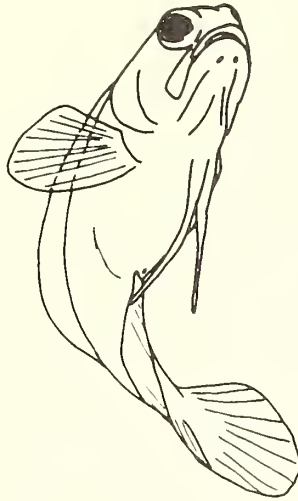
Tailfirst Entry. The fish enters the burrow caudal-end first while backing slowly. As outlined previously, the fish may passively retreat due to gravity and currents or actively swim rearwards. The pelvic fins are folded against the body during this and all other entries in order to clear the burrow opening.



TEXT-FIG. 2. The action of "hover": A) lateral view; B) ventral view; C) "hover" with the pelvic fins held against the body; D) "hover" with the pelvic fins extended.



TEXT-FIG. 3. Movements of the pectoral fins during hovering. A) The upstroke of the pectoral fin with the medial rays lagging. B) The downstroke of the pectoral fin with all rays brought back together.



TEXT-FIG. 4. The lateral turn (yaw).

Headfirst Entry. The animal turns from a normal hovering position in the water column and swims rapidly head foremost into the burrow.

Tailfirst to Headfirst Entry. The fish backs toward the burrow tailend first until the caudal fin is immediately above the opening. The jawfish then turns 180° and enters the burrow head foremost.

Exit. The fish emerges head first, using the pectoral fins for propulsion. The pelvic fins are held posteriorly against the body until the animal is clear of the mouth of the burrow. The pelvic fins may then be extended.

Sit. The animal maintains position in the burrow opening with only the head (to the level of the opercular margin) exposed. Methods used for holding this position include sitting on the sides of sloping burrow entrances and wedging the body in the opening.

Cover Burrow. The jawfish enters the burrow tailfirst and as it descends will bend laterally or ventrally and pick up a small stone or shell in its jaws. This stone is released covering the opening as the head of the fish passes into the burrow. This action is usually performed at dusk or when predators approach.

Adjust Cover. The stone or rock covering the burrow may be adjusted in its position by the fish pushing up from inside the burrow and moving the stone with its head.

Uncover Burrow. The burrow is uncovered by the fish by moving forward in the burrow

and pushing the covering stone out of the way with its head. The stone may then be moved by picking it up in the jaws if it is still blocking the opening. The action is usually performed at dawn or after the passing of predators.

Resting. That position within the burrow, whereby the fish rests on the substrate. All fins are folded, with the possible exception of the pectoral fins. This position is noted only at night. There is no apparent opening or closing of the mouth or the opercular apparatus.

Actions Related to the Maintenance of the Burrow

Dig. This action can be divided into three sub-actions which are not discreet motor patterns, but appear to have different functions.

A. Within burrow: Sand is scooped up in the mouth inside the burrow and it is then deposited outside the burrow near its margin (Plate III, fig. 4). When carrying sand, the branchial apparatus of the fish is expanded, the mouth closed, and the gill covers slightly open (Plate III, fig. 5). The dark line bordering the isthmus which is normally hidden is visible when the mouth is full of sand.

During periods of high current speed, the jawfish will use the current to its advantage in digging from the burrow. Rather than expelling the sand on or beyond the margin of the burrow, the fish will expell the sand vertically from its mouth without emerging fully from the burrow opening. The current will carry the sand over the burrow margin before it can fall.

B. Retrieve sand: Sand is scooped into the mouth at some distance from the burrow (Plate IV, fig. 6) and brought directly to the margin of the burrow where it is expelled. Again the dark line bordering the isthmus is visible when sand is being carried in the mouth. Movement of the caudal and pectoral fins is extremely rapid when swimming with the sand in order for the animal to stay above the bottom with this added weight.

C. Remove sand: Sand is scooped up from the margin of the burrow and carried some distance from the burrow where it is expelled. Again, the isthmus line is visible and the swimming rate rapid.

Retrieve Rock. This action, like "dig," is divisible into three sub-units.

A. Recover rock: A small stone or shell is picked up in the jaws and brought to the burrow where it is deposited on the margin. Carrying rocks differs from carrying sand in that the rock is held in the jaws while sand is carried inside the mouth. Also, sand must be forcefully expelled while the rock can be released by simply opening the jaws.

B. Remove rock: A small stone or rock is picked up in the jaws from the burrow margin and carried some distance away where it is deposited.

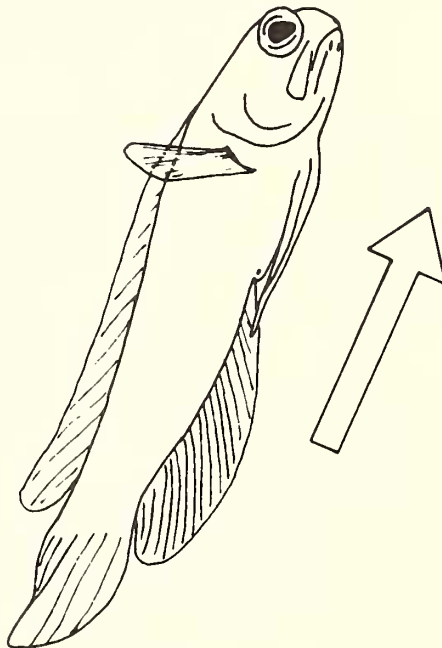
C. Remove rock from within burrow: The fish picks up a rock in its jaws inside the burrow, emerges headfirst, and drops the rock on the burrow margin (Plate III, fig. 7).

Adjust Rock. This action is performed with the body in the burrow with only the head exposed. Rocks on, or near, the burrow margin are picked up in the jaws and positioned on the margin. Often upon placing the rock in position, the jaws of the fish are not released and the rock is moved with the head to produce a more suitable resting place for it. Rocks may also not be removed from their original position but simply moved slightly to improve their positioning and that of surrounding rocks.

Actions Associated with Feeding

Thrust. The fish moves rapidly forward from a hovering position through the use of the pectoral and caudal fins. The animal comes to a quick stop through the use of the pectoral fins (Text-fig. 5).

Snap. The jawfish ingests a food particle by opening the mouth and creating a slight inrush of water by flaring out the opercular covers and spreading the branchiostegals (Text-fig. 6a and 6b). The line hidden under the maxillary is exposed when the mouth is opened, and the long axis of the pupil is oriented so the fish may see the food particle with binocular vision.



TEXT-FIG. 5. The action of "thrust."

Reject. The food particle is ingested as in a snap, but is quickly expelled from the mouth by a pulling in of the gill covers and branchial apparatus.

Maintenance Activity

Although the jawfish possesses several apparent maintenance activities, these will not be described since they were not quantified diurnally.

Actions Concerned with Interspecific Relationships

The interspecific relationships of *O. aurifrons* have previously been dealt with by Colin (1971). The action, chase, was the only activity for which diurnal data are available.

Chase. The act of chasing an intruding fish with jaws spread. It usually occurs within 20 cm of the burrow and the distance a fish is pursued varies a great deal. Swimming is carried out rapidly with the pectoral and caudal fins.

Actions Concerned with Intraspecific Relationships

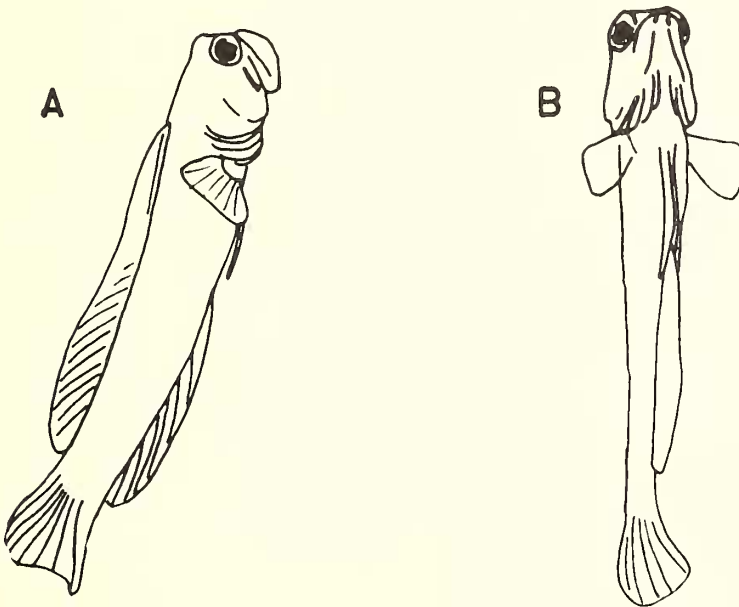
A variety of intraspecific relationships exist among individuals of *O. aurifrons*. Some of these have already been mentioned by Colin (1971), while others are described below:

Arch. This is the "lateral display" of Leong (1967). I feel the term "lateral display" is more suited for a different action involved in terri-

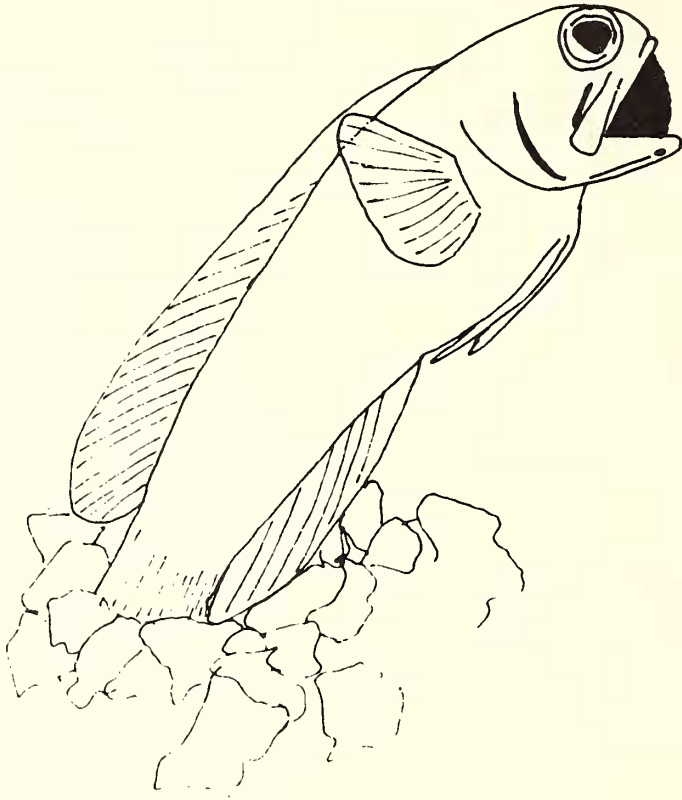
torial defense where one fish turns laterally toward another, with the body oriented nearly vertically and spreads the mouth, branchial apparatus, and isthmus to their maximum while the head is shaken laterally. Leong (1967) did not describe such an action for *O. aurifrons*.

The "arch" is performed by the male fish. This fish, swimming in the water column, will orient its body laterally toward a female and assume a horizontal position. The caudal and cephalic ends of the body are bent upward and the dorsal, anal, and caudal fins are spread to their maximum. Immediately after the body is bent, the branchial apparatus and the isthmus are dropped and the mouth is opened (Plate V, fig. 8). The spread of the mouth is not as great, however, as it is during the aggressive "lateral display." The isthmus, maxillary, and branchiostegal lines are all clearly displayed, and the arch position may be held for several seconds. Often after this action, both fish will enter one burrow for a period of several seconds. It is for this reason that the "arch" is considered as courtship behavior rather than some other type of intraspecific behavior.

Brood. The male fish broods the eggs orally (Text-fig. 7) and is positioned usually directly above the burrow entrance in a hovering attitude. The maxillary line is clearly exposed and the branchial apparatus not greatly expanded.



TEXT-FIG. 6. The action of "snap"; A) dorso-lateral view, B) ventral view.



TEXT-FIG. 7. The action of "brood."

The mouth is usually open but it can be nearly closed while carrying the eggs. Closing the mouth when the egg mass is being carried causes a consequent expansion of the branchial apparatus. The head is expanded somewhat laterally and the isthmus lines are apparent in a front view of the animal.

DAILY ACTIVITY PATTERNS AND BEHAVIORAL CORRELATIONS

In situ studies of coral reef fishes have been carried out only recently, and work dealing with *in situ* measurements of daily activity of coral fishes is extremely scarce. Some of the noteworthy studies are the following. Youngbluth (1968) worked with the Hawaiian, parasite-picking wrasse, *Labroides phthirophagus*, and determined feeding (cleaning) rates of these fish at two hour intervals during the day. No significant difference was found between morning and afternoon rates but feeding rates varied on different reefs. Albrecht (1969) studied the fanning of the nest by the pomacentrid, *Abu-*

defduf saxatilis, in relation to depth and time. His observations were both diurnal and nocturnal. Myrberg (in press) worked with the daily patterning of various sonic patterns in the pomacentrid, *Pomacentrus partitus*, and included observations both in the field and in laboratory aquaria.

During the present study, two individuals of *O. aurifrons* were sufficiently close to the UTV camera so that detailed observations and rather precise measurements of behavior could be carried out (2m). Four other individuals were approximately 8m away and although their position in the water column could be observed, lack of detail precluded behavioral measurements. The jawfish, male and female, had their burrows 60 cm apart.

This pair was closely observed for 25 days during the summer of 1969 and the frequency of certain actions was recorded for 30 minutes during each of seven periods throughout the day. Fifteen minutes of each period was de-

voted to the activities of each of the subjects. The onset of the periods was altered so that they maintained the same relative position in regards to the changing length of the daylight period. For example, the periods originally at 9:00 AM on June 24 was moved to 9:18 AM on Sept. 7 to keep the same position in total day length. The days spent observing and recording the behavior of *O. aurifrons* on the UTV included June 24 to 30, July 17 to 24, August 2 to 6, August 26 to Sept. 3, and Sept. 5 to 8, 1969. Preliminary observations but no quantification of behavior were carried out on June 4 to 6.

For purposes of recording various activities on a 12-channel event recorder, activity was broken down into four major groups: 1) feeding, 2) burrow oriented, 3) interspecific, and 4) intraspecific. Whenever possible an "indicator action" was selected to reflect the level of a certain type of activity. This "indicator action" is often not the most direct measure of a major activity group. Sevenster (1961: 17-18) for example, correlated the number of "zigzags" of the males of *Gasterosteus aculeatus* with the frequency of the male leading the female, a purely sexual activity. He then used the more easily observed "zigzag" as a measure of the sexual activity of the male instead of the less easily observed action of leading.

For *O. aurifrons* the "snap" was selected as an indicator action for feeding activity since it was easily observable and reflected reasonably well the actual food intake of the animal. The actions of "thrust" and "turn" were also considered possible feeding actions and their frequencies, along with those of "snap," were measured during the period June 24 to 30. Regression lines were calculated from these data (Text-figs. 8 and 9) and clear correlations were noted among the occurrences of these actions. Therefore, each could be considered as elements of feeding behavior and it was necessary to determine only the frequency of "snaps" in succeeding behavioral measurements.

Measurements were also made of the amount of time spent by a given fish in the water column above its burrow. The "Percent time in the water column" was subsequently determined, with those activities directed away from the water column, such as retrieval of sand, not being included in this percentage.

The seven observation periods during the day were numbered chronologically for reasons of analysis. Text-fig. 10 illustrates feeding activity, as reflected by the mean number of "snaps" per 15 minute period for each of the seven periods of the day. The feeding rate ("snaps") is fairly constant over the entire day considering all environmental conditions. Reaction to specific

environmental factors such as current speed and light intensity will be examined later.

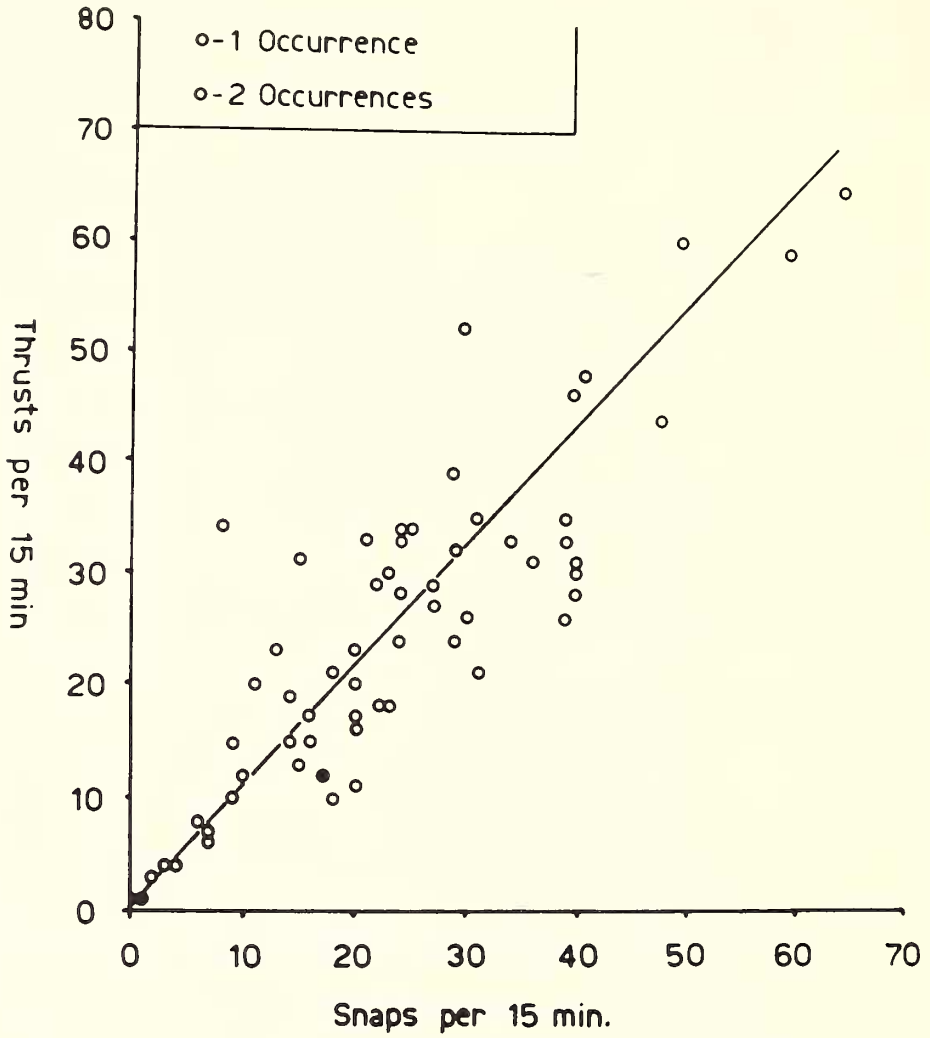
The relationships that exist among the actions involved in burrow oriented activity are more complex than those involved in feeding. Digging from within the burrow is commonly seen, but it cannot be considered to reflect the nature of the fluctuations shown by related activities such as: remove sand, retrieve rock, remove rock, and adjust rock (Text-fig. 11 and Table 1). These, therefore, must each be considered separately. Text-fig. 11, illustrating mean digs per 15 minutes, shows a strong peak (10.4) at the fifth period (3PM—start of study) subsequent to a moderate, but fairly consistent digging rate during the first four periods (4.6 to 7.3). There is a sizable decrease in the rate after the fifth period with a rate of only 1.6 at the seventh period (7PM—start of study).

Table 1 presents the mean values per 15 minutes of three other burrow oriented activities: removal of sand, retrieval of sand, and adjustment of rocks. The latter two show marked increases in the final three periods of the day with their greatest values being in the last period. Removal of sand differs since its peak value is during the first period of the day with only a slight increase in the afternoon.

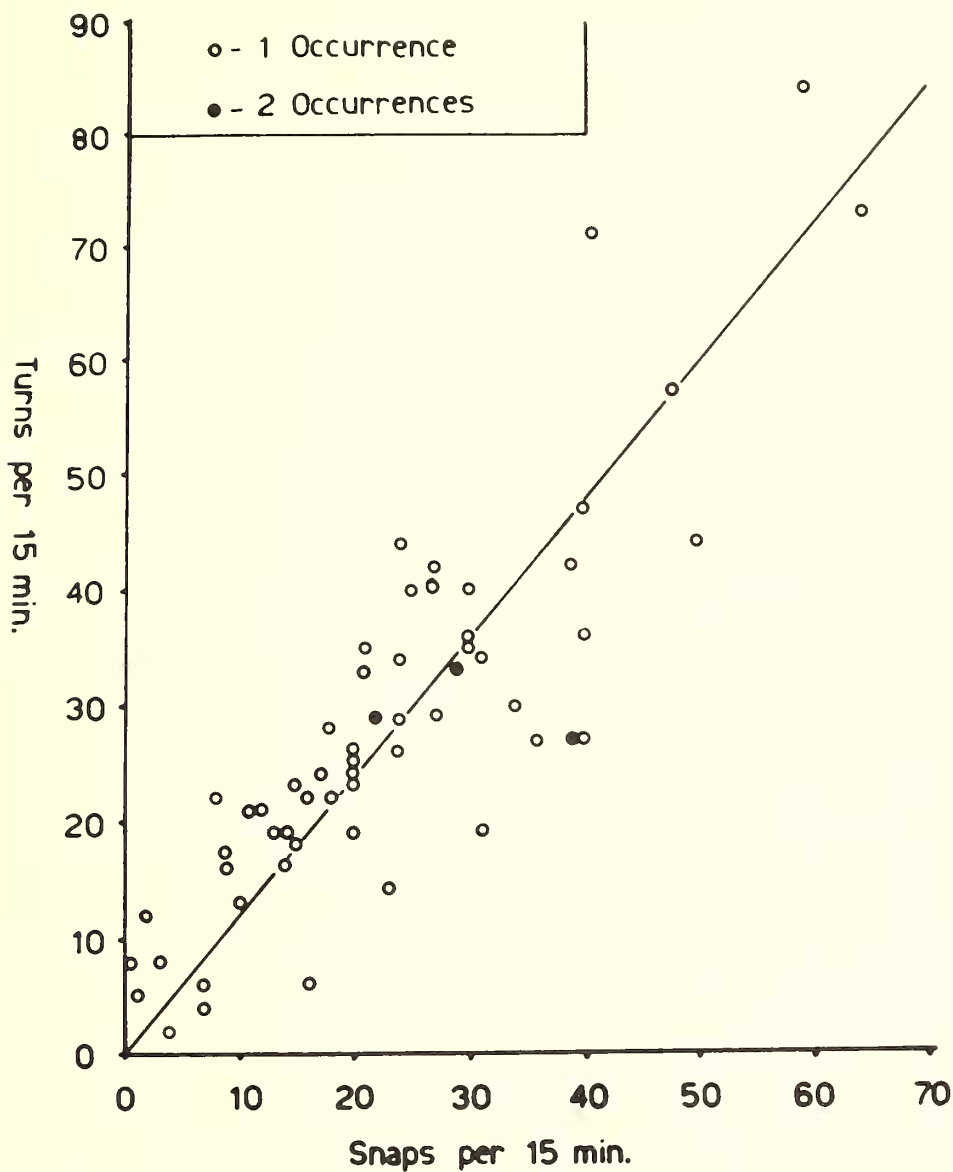
The frequency of the activity, chase, is shown in Text-fig. 12. The increased frequency of this activity in the last three periods of the day was probably due to an increase in the swarming behavior of various labrids at that time. *Hali-choeres bivittatus* and *H. garnoti* were very active during the final period of the day, often causing a jawfish to prematurely close its burrow for the night.

The frequency of flight reactions of *O. aurifrons* from other species of fishes was difficult to determine objectively. Often an approaching fish could not be seen on the UTV but the jawfish would flee to the burrow. Conversely, the fish has been observed to move rapidly to the burrow during the approach of a large fish, then emerge several seconds later with a mouth full of sand, as noted during a "dig." Such occurrences in the face of two equally possible stimulus situations preclude the use of possible flight responses in measurements of daily activity. Other aspects of interspecific activity have been considered elsewhere (Colin, 1971).

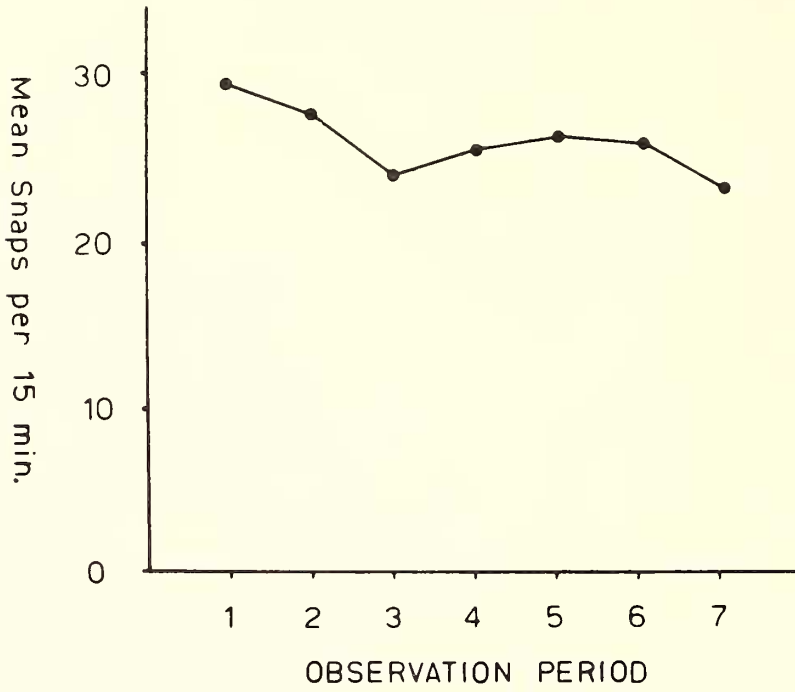
The occurrence of the probable male courtship pattern "arch," is shown in Text-fig. 13. Percent of total "arches" is plotted rather than a mean value since the sample size was rather small (35). Arching was most prevalent early in the morning and during late afternoon periods. Aquarium observations supported this finding, most arches occurring shortly after the burrow had been uncovered in the morning.



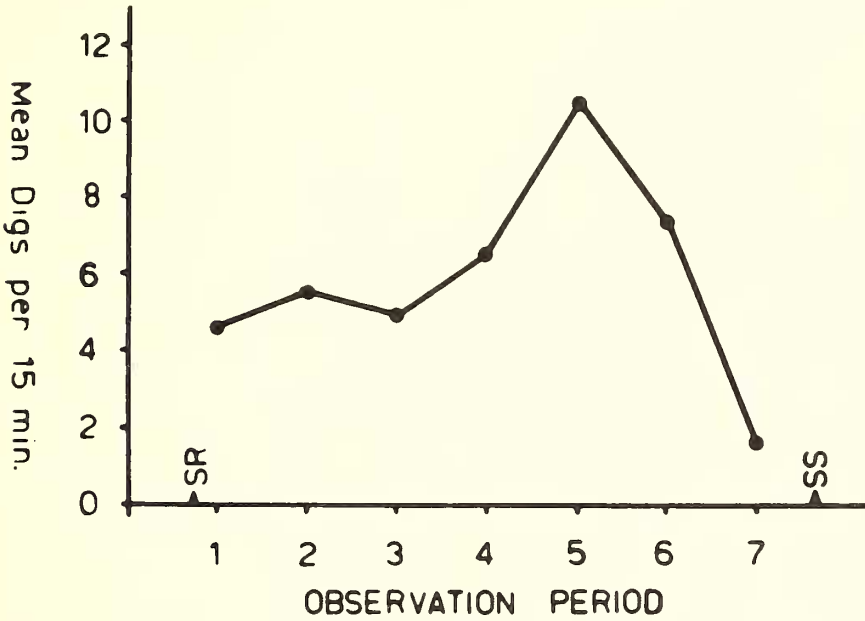
TEXT-FIG. 8. Correlation of the frequency of the actions of "snap" and "thrust."



TEXT-FIG. 9. Correlation of the frequency of the actions of "snap" and "turn."



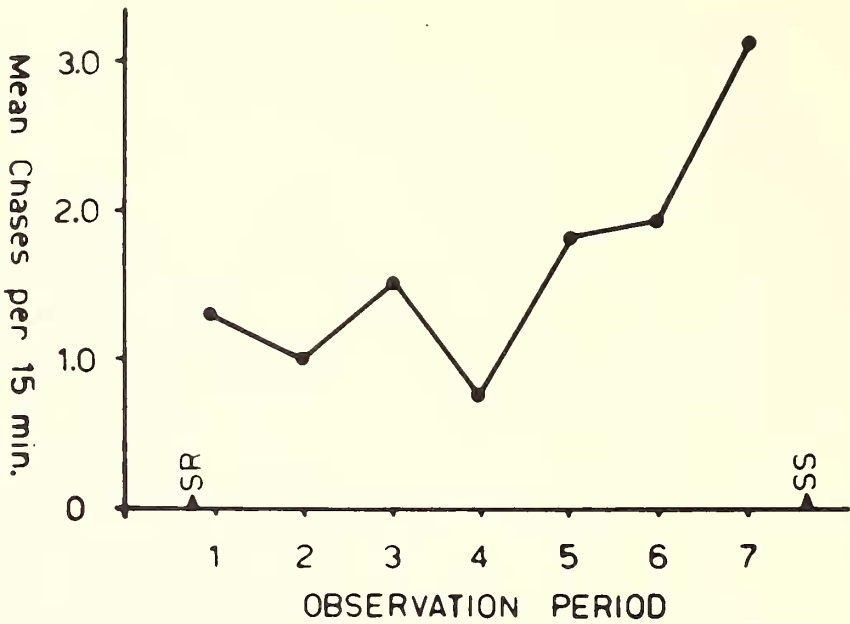
TEXT-FIG. 10. Diurnal patterning of the mean "snap" frequency of two specimens of *Opistognathus aurifrons* for a period of 25 days at the UTV site, Bimini, Bahamas.



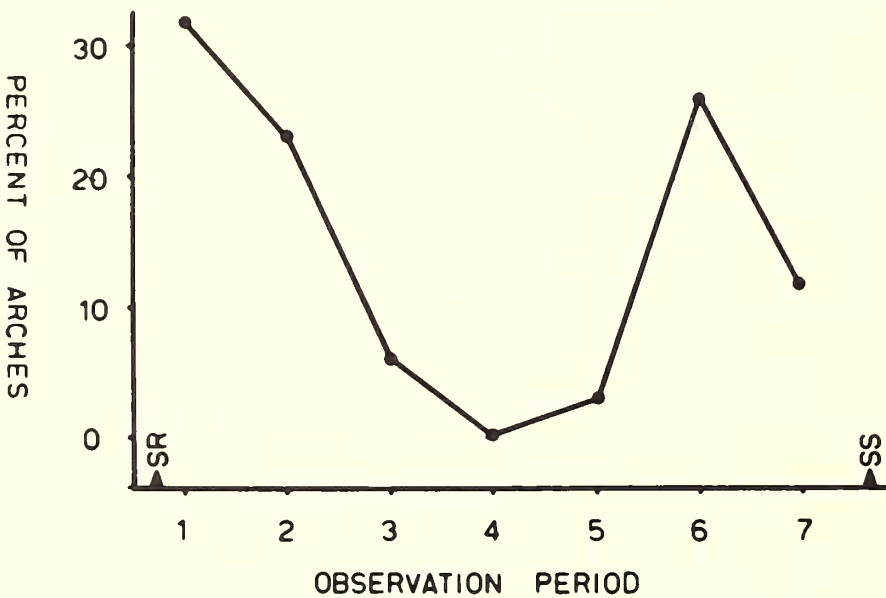
TEXT-FIG. 11. Diurnal patterning of the mean "dig" frequency for two specimens of *Opistognathus auri-frons* for a period of 25 days at the UTV site in Bimini, Bahamas.

TABLE 1. MEAN FREQUENCY OF BURROW ORIENTED ACTIONS PER 15 MINUTES FOR A PERIOD OF 25 DAYS

Period	Retrieve Sand	Remove Sand	Adjust
1	0.21	1.68	0.31
2	0.02	0.08	0.18
3	0.59	0.02	0.25
4	0.26	0.00	0.13
5	1.10	0.51	1.48
6	3.83	0.25	1.05
7	4.24	0.05	1.81
Total Number of Periods Observed 231			



TEXT-FIG. 12. Diurnal patterning of the mean frequency of "chase" for two specimens of *Opistognathus aurifrons* for a period of 25 days at the UTV site in Bimini, Bahamas.



TEXT-FIG. 13. Diurnal patterning of "arch" (given as percent of occurrence) for a period of 25 days at the UTV site, Bimini, Bahamas.

RELATIONSHIP BETWEEN FEEDING AND BURROW ORIENTED ACTIVITIES

The two major time-consuming activities of the field subjects were feeding and burrow oriented behavior. These two activities were inversely related since the first involved being in the water column and the second did not. Text-fig. 14 shows the mean number of "snaps" and "digs" against the percent time in the water column. As the time in the water column increases, the burrow oriented action ("dig") decreased and the water column oriented action ("snap") increased. However, the number of "snaps" or "digs" was not directly proportional to the percent time in the water column. The "snap" value at 50 percent time in the water column was only one-quarter of the value at 100 percent time in the water column, not one-half as would be expected if the feeding rate was constant over the entire period spent in the water column. Percentage values below 33 percent time in the water column were not observed in the field except when the fish remained in its burrow for known or unknown reasons for the entire 15 minutes. This is also discounting a few "aborted" periods where the jawfish was frightened into its burrow after a few minutes of normal be-

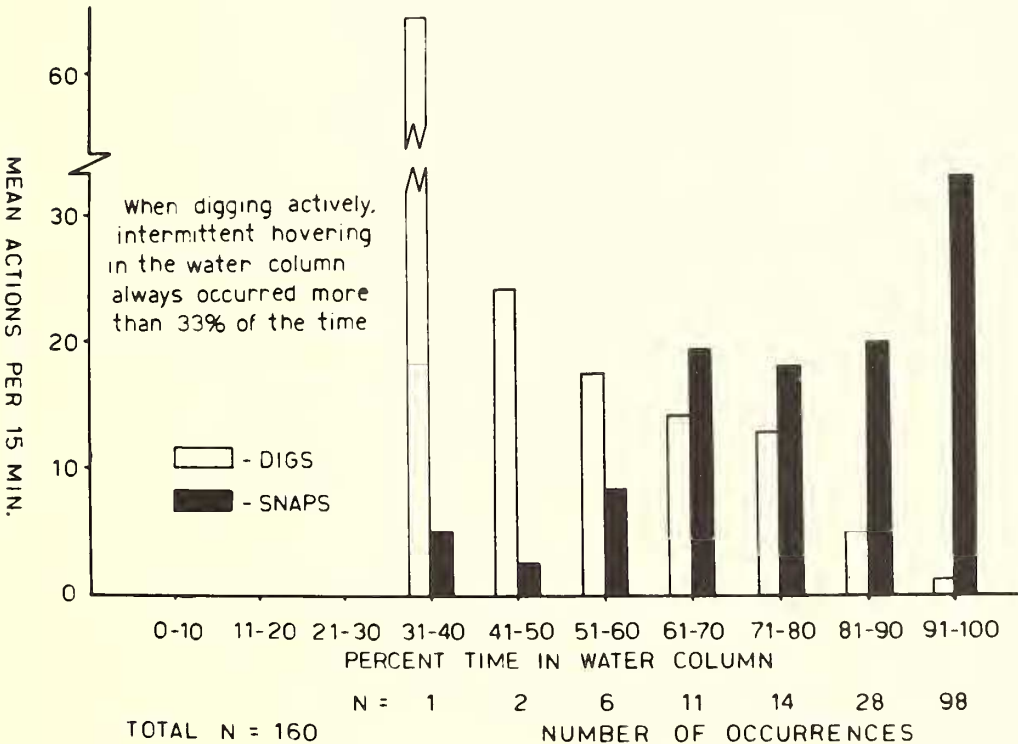
havior and remained there for the remainder of the observation period.

The explanation for the seeming paradox rests with both the behavior of the fish while digging and the length of the observation period (15 min.). Brief periods of hovering always interrupted separate bouts of digging, and such periods accounted for at least 33 percent of a given observation period.

There is little diurnal variation in the mean percent time spent in the water column as is shown in Table 2. Mean percentages from a low

TABLE 2. DIURNAL VARIATION IN MEAN PERCENT TIME IN THE WATER COLUMN

Observation Period	Mean Percent Time in the Water Column	Number of Periods
1	91.0	25
2	87.2	28
3	90.8	25
4	85.6	27
5	84.7	18
6	83.8	24
7	90.7	16



TEXT-FIG. 14. Relationship of mean "dig" and mean "snap" frequency to percent time in the water column.

of 83.8 to a high of 91.0 indicate that water column oriented behavior (feeding) dominated the total daily activity. This does not, however, reflect feeding effectiveness ("snap" rate) which can be altered by environmental conditions.

EFFECT OF CURRENT SPEED UPON VARIOUS ACTIVITIES

Current speed affects the "snap" frequency in combination with certain other conditions. Text-fig. 15 shows the mean "snap" frequency during observation periods when the current speed was greater than 0.20 knot. There is a sizable decrease in the mean "snap" frequency during the low light periods (periods 1, 2, and 7) in which high current speed was encountered.

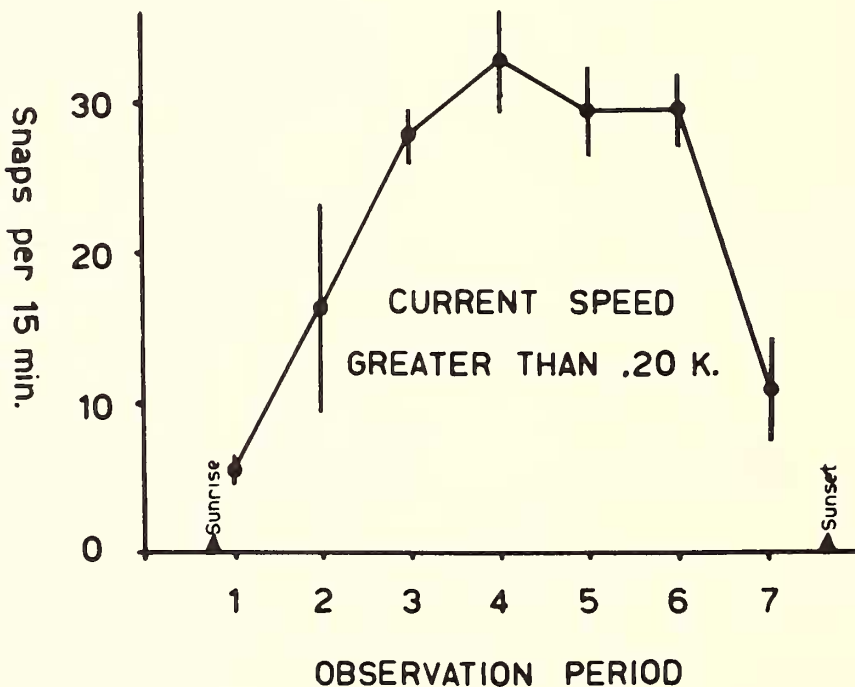
The "snap" frequency for periods where the current was 0.20 knot or less is shown in Text-fig. 16. In this case the "snap" rate was nearly constant throughout the day with only a slight dip at the third period.

The values at low light periods during high current speed shown in Text-fig. 15 are therefore being masked in Text-fig. 10 by the greater occurrence (85 percent of all observations) of currents 0.20 knot or less. During the winter, however, shorter days and generally less con-

sistent water conditions will no doubt increase periods of low ambient light and of high current speed.

It seems then that neither high current speed (0.20 knot or greater) nor low light conditions alone could produce any significant decrease in the frequency of "snaps." In fact, the mean "snap" frequency at periods 3 and 4 is greater for currents above 0.20 knot (Text-fig. 15) than for currents of 0.20 knot or below (Text-fig. 16). During high current, low light conditions, the fish does not move far from the burrow and instead hovers with the anterior posterior axis of the body near horizontal directly above the burrow opening. I feel that *O. aurifrons*, being mainly a visual feeder, probably requires a certain level of both light and current speed to feed effectively. Variation in only one parameter does not apparently affect the feeding rate.

Digging is also somewhat related to the current speed as shown in Text-fig. 17. The mean values of "digs" in periods in which digging occurred was similar for currents of 0 to 0.10 knot and for currents greater than 0.10 to 0.20 knot. The mean "dig" frequency showed a significant decline (at least 95 percent separation for currents greater than 0.10 to 0.20 knot and greater



TEXT-FIG. 15. Diurnal patterning of mean "snap" frequency of *Opisthognathus aurifrons* when current speed was greater than 0.20 knot at the UTV site in Bimini, Bahamas.

than 0.20 knot), however, for currents greater than 0.20 knot. The reasons for this decline are still unclear.

The action of arching also seems to be related to the current. Text-fig. 18 plots the percentage of "arches" observed against various current conditions. Almost three-quarters of the "arches" occurred when current speed was 0 to 0.05 knot, while these currents occurred in only one-quarter of the observation periods. Current speeds of 0 to 0.10 knot were observed in 52 percent of the periods, yet over 90 percent of the arches observed occurred during this current speed regime. Additionally no arching was observed at current speeds over 0.20 knot. Since the arch is a complex posture supposedly directed at a female, the utility of performing this action under current conditions where the displaying fish is not quickly carried away by the current is obvious.

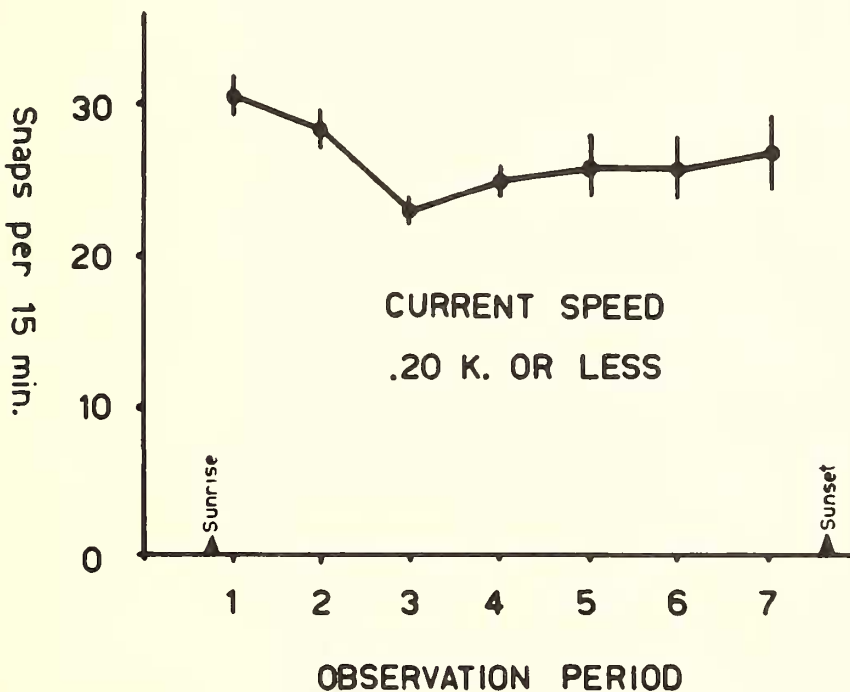
The percent time spent by the fish in the water column possibly varied with the current and this might easily explain the results shown in Text-fig. 15 (currents speed greater than 0.20 knot versus "snap" frequency) and in Text-fig. 18 ("arches" versus current speed). But Table 3 shows that the mean percent time in the water column was independent of the current speed.

The parameter of current direction was recorded with current speed data but it showed no correlation with any behavioral measurements. The only change seen in the fish was a change in the direction in which they faced in order to swim into the current. During periods of slight or no current speed, the swimming direction of the fish seemed random except when an apparent food item was sighted.

EFFECT OF OTHER ENVIRONMENTAL FACTORS UPON VARIOUS ACTIVITIES

Temperature measurements were also made at the time behavioral data was taken, but stability of temperature during the study (29° to 31° C) precluded meaningful correlations with behavior. Temperatures near the winter low of approximately 20° C might produce considerably different results. Yellowhead jawfish, kept in aquaria, become very inactive at temperatures approaching 20° C and feed very sparingly. Below 20° C the animals spend most of their time in the burrow, and at 17° C appear near their lethal lower temperature limit.

Atmospheric conditions at the UTV site were also considered, qualitatively, as possibly influencing behavior. Numerous thunderstorms and



TEXT-FIG. 16. Diurnal patterning of mean "snap" frequency of *Opistognathus aurifrons* when current speed was 0.20 knot or less at the UTV site in Bimini, Bahamas.

heavy rain, which could be heard at the site via the submerged hydrophone, seemed to have no effect on the activity of the fish. Surging of currents on the bottom (depth 20 m) produced by surface waves resulted in movements of grass blades and bits of detritus. These occasionally rolled along the bottom and entered burrow openings. Such objects were quickly removed by the fish from the burrow.

Turbidity measurements were not made, but increased turbidity no doubt affects the activities of jawfish since any decrease of ambient light reduced visibility. Such reduction might well cut the feeding effectiveness of the animal as well as reducing its range of movement.

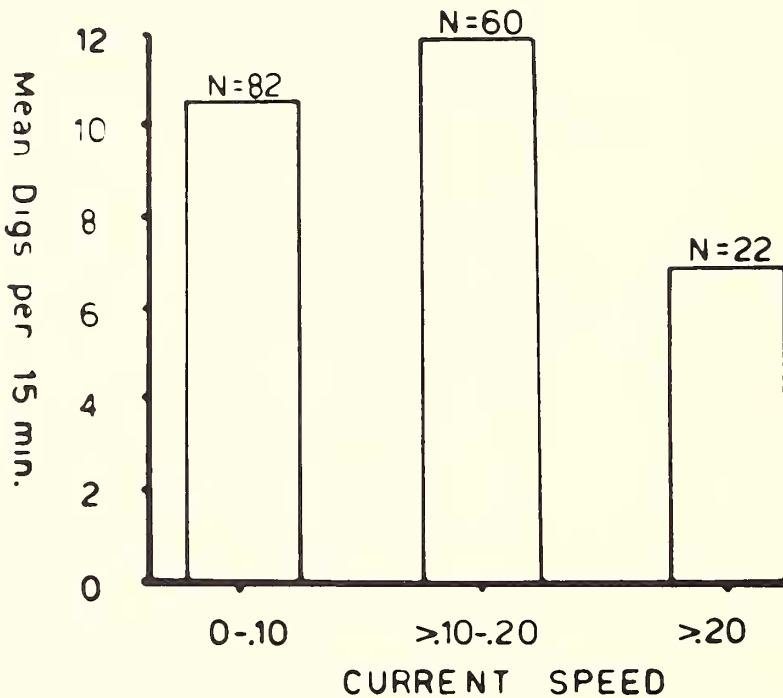
SONIC ACTIVITY

Extended listening has been unproductive in detecting any sonic activity by *O. aurifrons*. A hydrophone was positioned less than one-half meter from the fish at the UTV site for the duration of the study, and several hours were spent listening with hydrophones in laboratory aquaria at various times of the day, but the results from this monitoring have been negative.

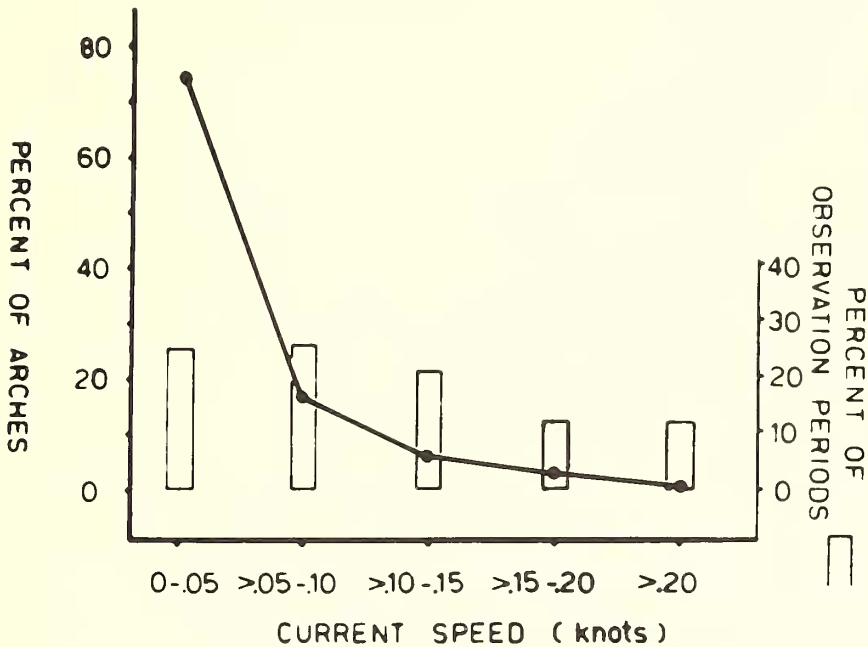
TIME OF COVERING AND UNCOVERING THE BURROW AND NOCTURNAL BEHAVIOR

Opistognathus aurifrons covers its burrow opening in the evening with a small rock or shell and remains within the confines of the burrow until the morning when the rock is removed. Table 4 presents the results of numerous observations on the time and conditions of the opening and closing of the burrow.

The time at which the burrow is uncovered during the morning varies from ten to 12 minutes before to a very few minutes after sunrise. Mornings with clear skies tended to have early uncoverings and mornings with late uncoverings were usually overcast. The fish tended to rise two or three minutes after the first objects on the bottom were visible on the UTV. This time of first visibility, of course, varied with the sky conditions. Aquarium fish will uncover the burrow any time during the night if lights are turned on, but the time required for this to happen was generally longer (as much as 10 to 15 minutes) during late night and early morning hours. When the lights were turned on at the normal uncovering time, the fish usually removed the cover of the burrow in less than one minute.



TEXT-FIG. 17. Relationship of current speed to the mean number of "digs" by *Opistognathus aurifrons* during periods in which digging occurred.



TEXT-FIG. 18. The relationship of percent of "arch" and percent of occurrence of various current speed regimes to the current speed.

TABLE 3. VARIATION IN MEAN PERCENT TIME IN THE WATER COLUMN WITH CURRENT SPEED

Current Speed	Mean Percent Time in the Water Column	Number of Periods
0.00-0.10 Knot	88.9	82
greater than 0.10-0.20 K.	85.9	60
greater than 0.20 K.	90.5	22

Light is probably a major controlling factor in determining the uncovering time. As day length changed, the time of uncovering the burrow was altered to match the changing sunrise time. On mornings when ambient light was low due to atmospheric conditions, this was reflected by a later rising time.

A different situation existed with respect to the time of covering the burrow in the evening. Times of from 92 minutes before sunset to six minutes after sunset have been recorded. However, many factors apparently entered into the determination of the closing time. The presence of other species in the area seems to have a definite effect. Large numbers of the fishes *Halichoeres bivittatus*, *H. garnoti*, and *Pseudupeneus maculatus*, browsing on the substrate near territories of *O. aurifrons*, often coincided with an

immediate retreat to the burrow and a covering of the mouth of the burrow with a stone. If this occurred near dusk, the fish often remained in the hole for the night.

Light appeared to control the absolute limits of time for closing the burrow. One-third of all closings occurred between sunset and six minutes thereafter (maximum limit).

A series of night dives on colonies of *O. aurifrons* by the author on the Florida reef tract in 1969 showed no evidence of any nocturnal activity. This agrees with Starck's (1966) statement "at night it (*O. aurifrons*) has never been found, and is apparently inactive." Fish in various aquaria (40 to over 2000 liters) also remained in their burrows the entire night as evidenced by irregular frequent inspections.

TABLE 4. TIME OF UNCOVERING AND COVERING THE BURROW BY *Opistognathus aurifrons*

Uncovering in the morning		
Time in minutes before (+) or after (-) sunrise	Number of occurrences	Percent of occurrences
greater than +10	2	13.3%
+10 to 0	10	67.0%
-1 to -10	2	13.3%
greater than -10	1	6.7%
Covering in the evening		
Time in minutes before (+) or after (-) sunset	Number of occurrences	Percent of occurrences
greater than +20	9	33%
+20 to +10	1	4%
+10 to 0	8	29%
-1 to -10	9	33%

MORNING AND EVENING BEHAVIOR

The present section deals with those events which immediately followed opening and preceded closing the burrow. The activities occurring during these two periods of the day are extremely different.

Text-fig. 19 shows that after opening the burrow in the morning, the fish quickly entered the water column with a resultant decrease in the time spent in the burrow. The time spent within the burrow opening (neither completely out or in the burrow) reaches a peak five minutes after opening the burrow, but it never occupies a significant percentage of the fish's time. Feeding began as soon as the fish entered the water column; after only four minutes the frequency of "snaps" was practically equal to the mean daily frequency (see Text-fig. 10). Burrow oriented activities such as digging and retrieving were non-existent in the early morning period, and interspecific activity was rarely observed.

Actions which immediately preceded closing the burrow in the evening were considerably different than those following its initial opening. A striking increase in both "adjust rock" and "retrieve sand" (Text-fig. 20) demonstrated that individuals physically prepare their burrow for the night. The adjustment of rocks may serve to prepare the opening for its covering stone, and the retrieval of sand to hide the stones of the burrow rim or to provide for a better fit for the covering stone. One covering stone is not reserved for use day after day, but a suitable stone, often one-half of a bivalve mollusc shell, is selected shortly before dusk and placed near the burrow opening.

Feeding declined in the final minutes (Text-fig. 20), but a low level remained up to the

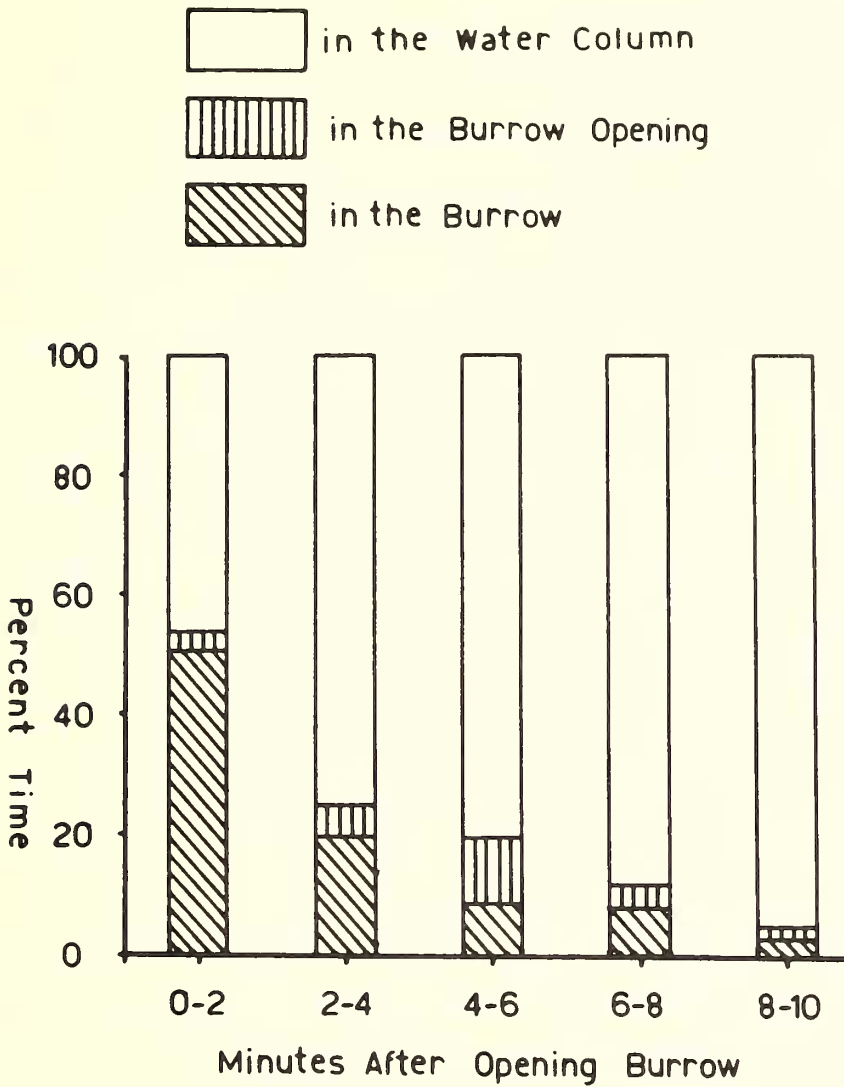
moment that the burrow was closed for the night.

RANGE AND TERRITORY

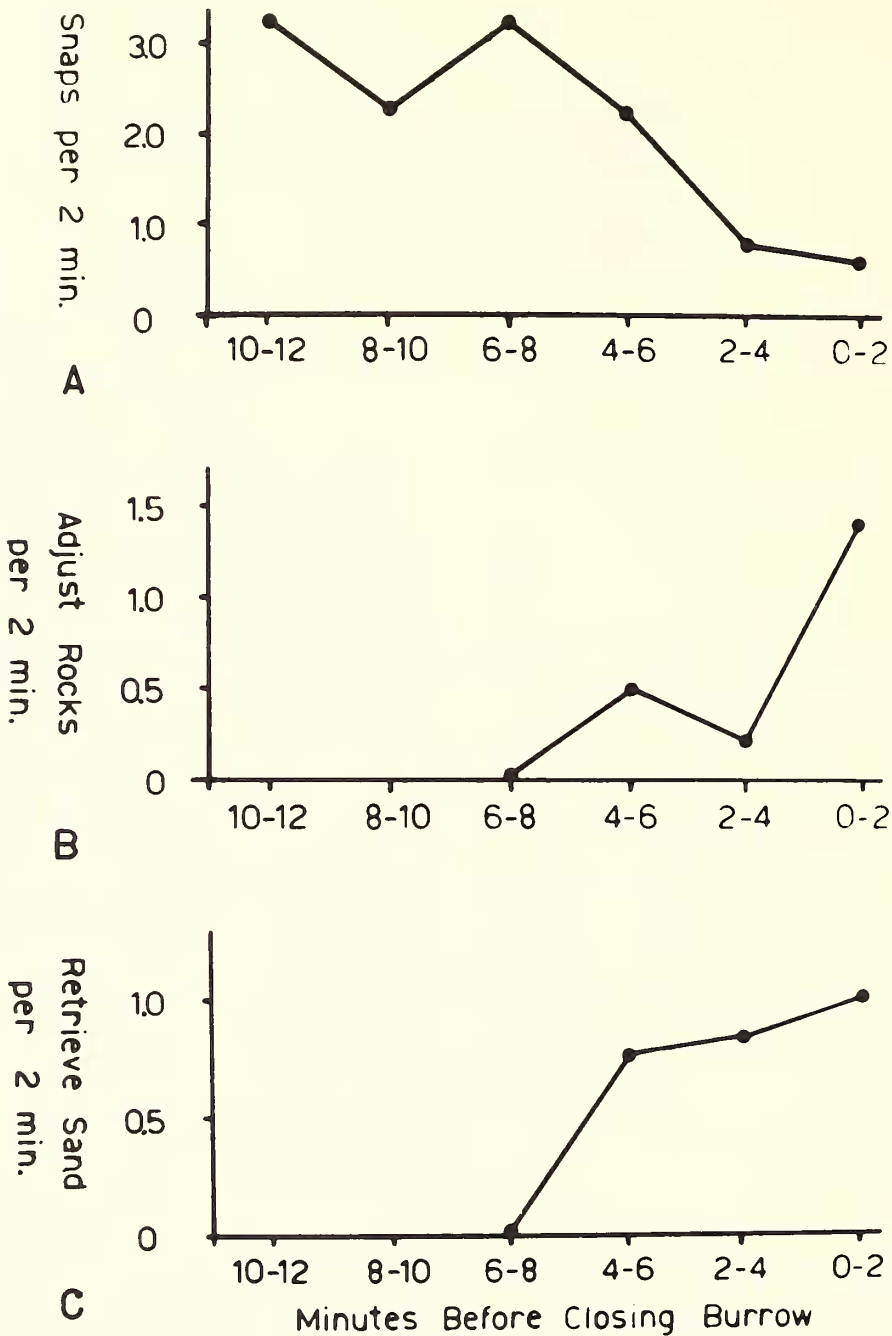
The concepts of range and territory are separate entities. The word, range, implies the total area into which an individual confines its presence. Territory, however, is a somewhat more elusive concept bringing to mind that area which an animal "considers" its own and is willing to defend. Often the territory of an animal depends upon the type of intruder that is encountered. The burrow of *O. aurifrons* may logically be considered the "center" of both its range and territory with the level (or intensity) of defense decreasing rapidly with distance from that point.

The territory was defended only against those fishes that are nearly the same size or smaller than *O. aurifrons*. Its efforts at territorial defense are minor compared to other species of reef fish, such as members of the genus *Pomacentrus* (Emery, 1968a; Myrberg, in press). Small fishes would be chased from a circle 20 to 25 cm in radius, with the burrow at its center. Fishes beyond this distance were apparently "watched" but no aggressive actions were directed toward them.

The range of the yellowhead jawfish should be considered from two aspects. The first is the feeding range which in benthic feeding fishes includes horizontal movement. Since *O. aurifrons* is a plankton feeder, this range also included vertical movement above the bottom. Text-fig. 21 presents the modal height and also the greatest height seen in any one period during given periods throughout the day. Heights greater than one meter could not be quantitatively measured, since there was nothing visible behind the fish for sight reference. The greatest



TEXT-FIG. 19. Percent of two-minute periods spent in various locations by *Opistognathus aurifrons* after opening the burrow in the morning at the UTV site in Bimini, Bahamas. All values are the mean of six observations.



TEXT-FIG. 20. A) The occurrence of "snap" by *Opisthognathus aurifrons* before closing the burrow for the night. Mean of ten observations. B) The occurrence of "adjust rock" by *O. aurifrons* before closing the burrow for the night. Mean of ten observations. C) The occurrence of "retrieve sand" by *O. aurifrons* before closing the burrow for the night. Mean of ten observations.

height ever reached by the animals was estimated about one-and-one-half meters above the bottom.

The low heights reached during the morning and evening hours were probably the result of low light levels, and this apparent adaptation no doubt provided greater chance for avoidance of predators. The horizontal component of the vertical ranging of the animals was at most 2 m, but seldom more than 1 m from the burrow opening.

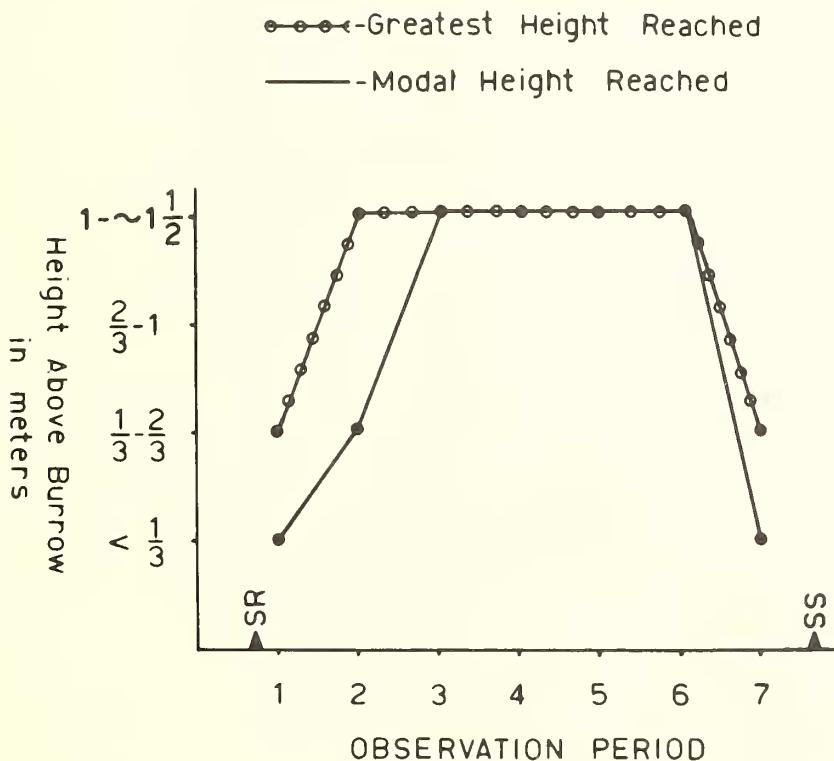
The second aspect of range to be considered is that having to do with rock and sand retrieval. The number of rocks which a fish considers suitable for its burrow in a given area must, of course, be limited. If these are used in burrow construction, the fish must then extend this range to retrieve additional ones. At the UTV site the range for rock retrieval was approximately 2 m. The fish would take a zigzag course outward inspecting various stones until a suitable one was found. The return course was direct, straight to the burrow.

The range for retrieval of sand was considerably smaller (generally less than $\frac{1}{2}$ m) due, no doubt, to the easy availability of suitable sand.

Rock stealing (i.e., taking rocks from the burrows of conspecifics) is often mentioned in the popular literature. In the field, this behavior was seldom seen, but evidently occurs more often under aquarium conditions. This is probably due to crowding and lack of sufficient rocks for proper burrow construction. In a 3000 liter laboratory aquarium with a bottom area of nearly one-quarter square meter for each of 15 fish, rock stealing was rare since the aquarium allowed a reasonably natural density of fish.

COMPARATIVE RELATIONSHIPS AND DISCUSSION OF THE ECOLOGY OF *Opistognathus aurifrons*

The sandy areas bordering reefs possess several characteristic species of fishes. Included in this group are the sand tilefish, *Malacanthus plumieri*; the gobies, *Ioglossus calliurus* and *I. helenae*; the bridled goby, *Coryphopterus glaucofraenum*; the garden eel, *Nystactichthys halis*; and *Opistognathus aurifrons*. All are burrowers of one sort or another, and all are colored for concealment against a white sand background. Two species, the gobiid *I. calliurus* and the heterocongrid *N. halis*, are amazingly simi-



TEXT-FIG. 21. The diurnal patterning of greatest and modal height reached by *Opistognathus aurifrons* above the burrow. Heights above one meter could not be quantitatively measured and were only estimated.

lar to *O. aurifrons* in the way they "make their living."

Specimens of *I. calliurus* known only from Florida waters hover in the water column and probably feed on floating plankton as does *O. aurifrons*. Randall (1967b) reports its West Indian congener, *I. helenae*, to feed entirely on floating plankton. *I. calliurus* enters burrows head-first on the approach of danger and has been seen by the writer performing lateral displays directed toward conspecifics for unknown purposes. Pairs often reside in one burrow which has a narrow vertical tunnel. Often groups of *I. calliurus* were found extremely close to yellowhead jawfish colonies on Florida reefs, but never within their boundaries.

Nystactichthys halis, attaining a length of one-half meter, does not hover as the others, but merely extends a portion of its body out of the burrow (Böhlke, 1957). It picks small zooplankters out of the water column (Randall, 1967a) while remaining partially within its burrows. The position of its eyes, as well as the shape of its pupils, is similar to *O. aurifrons* and probably enables it to utilize binocular vision in picking plankton.

A plankton-feeding existence imposes certain restrictions on the activity of a fish. A major portion of its time must be spent in feeding, due to the small size and spacing of food particles. For example, *O. aurifrons* spends practically 90 percent of the daylight periods feeding. Recent work by Emery (1968b) on the plankton within the reef ledges and caves may modify some of these generalities, since in these localities tremendous amounts of zooplankton are readily available to reef fishes. Most plankton-feeding fishes visually detect their prey. Such feeding is expedited by binocular eyesight and such activity is restricted to diurnal periods. A notable exception to this rule may be the apogonid fishes, which apparently locate plankton visually at night (Randall, 1967a). Most other plankton-feeding fishes are inactive at night.

Some of the western Atlantic congeners of the yellowhead jawfish, *Opistognathus macrognathus*, *O. maxillosus*, and *O. whitehursti*, differ greatly in behavior, food habits, and coloration. They 1) do not hover; 2) feed primarily on benthic forms and free swimming forms living near the bottom (Randall, 1967a); and 3) are brownish, dusky, or mottled in coloration. In addition they are often found in areas of turbid water.

Nothing is known of the food habits of the congeners of *O. aurifrons* typically found in clear water, i.e., *O. lonchurus* and *O. gilberti*. Both species have been reported not to hover as *O. aurifrons* (*O. gilberti*, Böhlke, 1967; *O. lonchurus*, Böhlke, 1967, W. A. Starck, pers.

comm.), and it seems likely they are not particulate plankton-feeders. *Opistognathus aurifrons* may well be the only plankton-feeding member of the genus *Opistognathus* in the western Atlantic.

The clear-water group of *O. aurifrons*, *O. lonchurus*, and *O. gilberti* apparently do not overlap in their ecologic distribution. *O. gilberti* is known only from the Bahamas and some areas of the Caribbean, typically on steep slopes in water 28 to 47 m in depth (Böhlke, 1967). *O. lonchurus* may be continental in distribution at depths between 38 and 93 m, and apparently prefers siltier sand conditions than *O. aurifrons* (Starck, pers. comm.). It is not found near the rocky outcrops associated with *O. aurifrons*. The only area along the Florida coastline where such substrate conditions are found in combination with clear water is seaward of the deep reefs, the latter terminating at a depth of about 30 m. It may well be that the distribution of *O. lonchurus* is determined by substrate and water conditions, not by depth. A case in point is seen at Triumph Reef, Florida; substrate conditions similar to those on the shallow reef are found to a depth of 50 m, and in this area *O. aurifrons* is abundant and *O. lonchurus* absent.

Opistognathus macrognathus, a species found in Florida in shallow water, has also been taken occasionally at Triumph and Long Reefs to a depth of 45 m. Several specimens have been taken near to *O. aurifrons* colonies; in one case a specimen was collected from a burrow only 60 cm distant from a yellowhead jawfish burrow.

Few reef fishes live in colonies. One clear exception to this is the yellowhead jawfish. Members of this species are reluctant to stray more than a few meters from their burrow, and this requires that the fish live close together for purposes of reproduction. Competition for food, which might be critical in benthic feeding fishes, is eliminated by the constant influx of plankton with the movement of water immediately above the burrows.

Little is known of the larval life of *O. aurifrons*. Specimens of *O. macrognathus* reared in aquaria metamorphosed from free swimming larvae to burrow dwelling juveniles 18 days after hatching. It seems likely that *O. aurifrons* has a similar larval development. How long individuals can remain as planktonic larvae will, of course, limit the distributional abilities through currents of this species.

Spawning extends at least from spring through late autumn. Fishes brooding eggs have been observed at the following locations on the dates given: Triumph Reef, Florida, May 27; Bimini, Bahamas, May 25, June 2; Serranilla Bank,

Oct. 5. Whether a female will spawn more than once per season is unknown, but it seems likely since multiple spawning of *O. macrognathus* about two weeks apart have occurred in aquaria.

The short larval life of jawfishes is advantageous since this period is the time of greatest predation. Unhatched fish are protected by the brooding parent and the burrowing, mature and immature fish have effective means of avoiding predation. This type of larval life, however, reduces genetic interchange over long distances, and coupled with the reduction in genetic exchange due to the non-wandering habits of the adults may result in the variability of this species over its geographic range. The occurrence of one "Bahama type" specimen in a group of Florida Keys specimens (Böhlke, 1967) may indicate that larvae may rarely get across open water barriers, such as the Florida Current, or that such variants occasionally are produced. Whether this occurs with sufficient regularity to keep the populations from moving farther apart is not known.

The significance of the dark head markings apparently used in behavioral displays and their absence in Florida specimens is not understood. The behavioral actions of Florida specimens are similar, if not identical, with those produced by Bahama specimens. Aquaria, containing members of both populations, might provide interesting insight into differences between these populations, e.g., whether the members of the populations are reproductively isolated for physical or behavioral reasons (presently unknown).

Various morphological adaptations of *O. aurifrons*, not present in the less specialized members of *Opistognathus*, are interesting when viewed from a behavioral-ecologic standpoint. The yellowhead jawfish possesses recurved canine teeth on the lower jaw; yet these are not needed in the capture of food which consists of planktonic animals. It seems likely that these teeth are an aid in carrying large rocks which would otherwise easily slip out of the jaws. This therefore appears to be advantageous for life in a rubble-strewn, calcareous sand area. Similarly in this species, the large mouth is needed not for feeding but appears to be essential only for digging and brooding the young.

The coloration of *O. aurifrons*, unusual among jawfishes, is again an apparent adaptation to the environment. The fish blends well against a white sand background.

Behavior can be thought of as a product of the environment. As previously discussed, the plankton-feeding existence imposes certain requirements on behavior and the burrowing existence also imposes its own set of restrictions. In combination, these restrictions require that

the fish have as the spatial center of its activity the burrow, yet spend the major portion of the daylight period in the water column feeding out of contact with the burrow. This results in the retreat behavior observed and accounts for the great wariness of this fish. It also makes colonial existence advantageous with the resultant effects on intraspecific behavior and genetic interchange. An organism reflects the requirements of its environment through appropriate behavior; and this, in turn, is seen most readily through the various adaptations that exist for a given ecological niche. The yellowhead jawfish is a most instructive creature for demonstrating this reflection and the apparent success of its adaptations for its "chosen" niche.

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Dr. Arthur A. Myrberg, Jr., made the full facilities of the Bimini video-acoustic installation available and his help and advice were invaluable. Dr. C. Richard Robins, Dr. Lowell P. Thomas, and Dr. Leonard J. Greenfield also gave advice and contributed to the study. Dr. Robins kindly loaned photographs and motion pictures of *O. aurifrons* taken by Walter R. Courtenay and himself at the Miami Seaquarium.

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PLATE I, FIGURE 1. A Bahamian specimen of *Opistognathus aurifrons* at the mouth of its burrow.

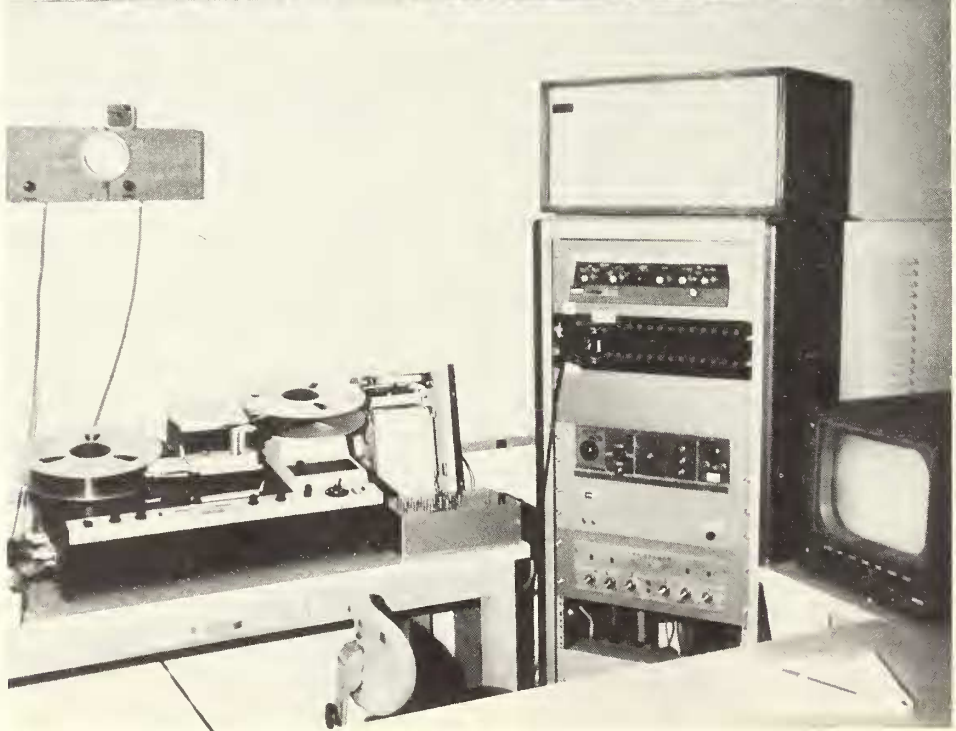


PLATE II, FIGURE 2. Underwater television (UTV) installation located at a depth of 20 m one mile off the coast of North Bimini, Bahamas.

FIGURE 3. Monitor room for the UTV system located at the Lerner Marine Laboratory. Visible are the control console, television monitor, event recorder, and video tape recorder.

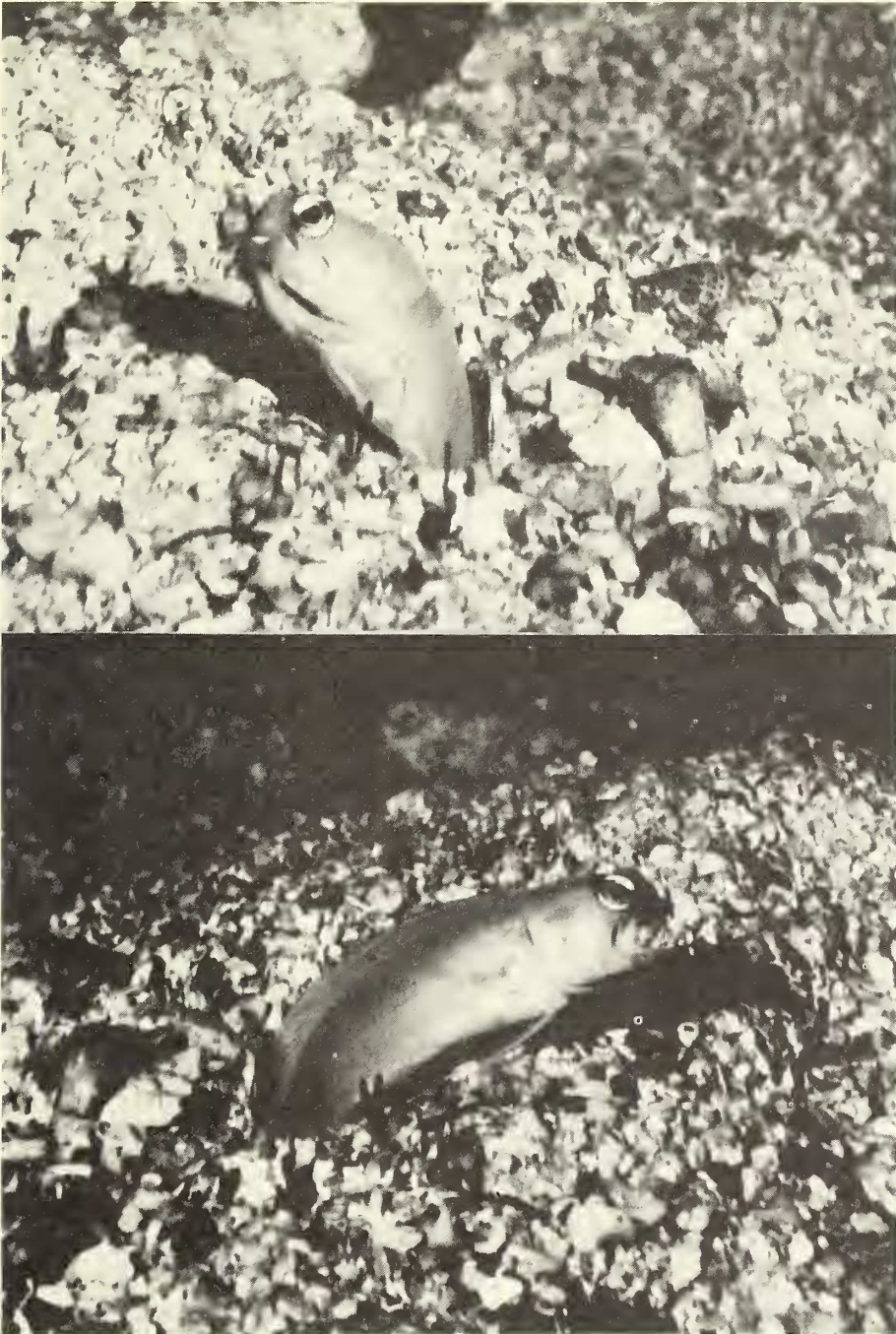


PLATE III, FIGURE 4. The action of "dig" (within burrow) performed by an individual of *O. aurifrons*. The dark line on the isthmus, normally hidden by folds of skin, is clearly exposed.

FIGURE 5. Lateral view of the action of "dig" (within burrow) performed by an individual of *O. aurifrons*. At this point the sand is being expelled from the mouth.



PLATE IV, FIGURE 6. The action of "dig" (retrieve sand) performed by a specimen of *O. aurifrons*. This action is performed some distance from the burrow opening.

FIGURE 7. The action of "retrieve rock" (remove rock from within burrow) performed by an individual of *O. aurifrons*.

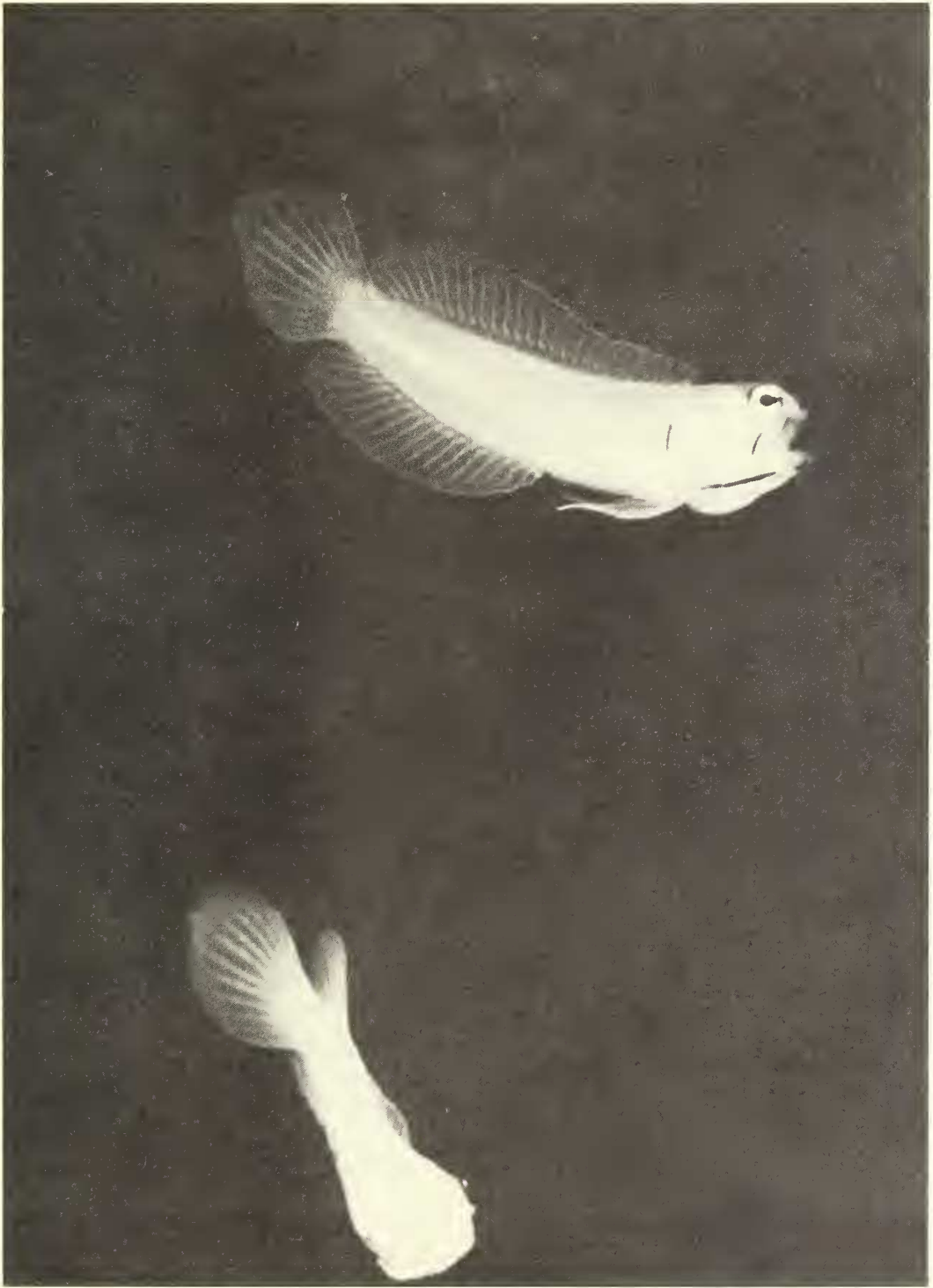


PLATE V, FIGURE 8. The action of "arch" performed by a male specimen of *O. aurifrons*. The male (upper fish) arches the body, spreading the fins, then opens the mouth exposing the various dark lines on the head. The lower fish is a female.